Exploring Electrified CO_2-to-Light Olefins: A Margin Study for Future Industrial Symbiosis

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Introduction

Global demand for light olefins continues to grow steadily. Recent market analyses indicate that global ethylene production capacity is expected to increase from approximately 158 Mt in 2026 to around 194 Mt by 2031, corresponding to a compound annual growth rate (CAGR) of approximately 4.2%. During the same period, global propylene capacity is projected to increase from roughly 147 Mt to about 188 Mt, corresponding to a CAGR of approximately 5.0%. At the same time, the geographical distribution of petrochemical production is changing significantly. Over the past decade, ethylene production capacity in China has expanded rapidly, while the United States has strengthened its position through the availability of low-cost ethane derived from shale gas. In contrast, European ethylene capacity has declined due to higher feedstock costs and stricter environmental regulations. The European Union Emissions Trading System (EU ETS) further increases production costs for energy-intensive industries by introducing carbon pricing mechanisms. Producing one tonne of ethylene from naphtha feedstock emits approximately 1.135 t CO_2-equivalent, while ethane-based cracking emits around 0.84 t CO_2-equivalent. Based on the average EU carbon price of €49.81/t CO_2, this corresponds to an additional cost of approximately €56/t ethylene for naphtha-based production. As carbon prices are expected to increase further, the competitiveness of European petrochemical production is likely to face additional pressure. These challenges have stimulated research into alternative production pathways that combine decarbonization with industrial competitiveness. Electrified chemical processes that integrate renewable electricity, hydrogen production, and catalytic CO_2 conversion represent a promising approach. In particular, processes based on co-ionic electrochemical membrane reactors (ci-EMRs) could enable the direct conversion of CO_2 and hydrogen into hydrocarbons. This study investigates the techno-economic potential of electrified light-olefin production by examining the influence of reaction selectivity, electricity price, and electrolyzer technology on process margins[1-3].

Materials and methods

This study performs a parametric techno-economic screening of electrified light-olefin production from CO_2 and hydrogen under conditions relevant to European refinery-integrated petrochemical systems. The analysis is normalized to 1 tonne of total olefins (ethylene + propylene) and evaluates how reaction selectivity (16%, 21%, 24%) and electricity price (€74, €92, €112/MWh) influence economic performance. Product value is calculated from the market value of all product streams, with two cases considered: hydrogen treated as a co-product or internally recycled. Electricity cost, dominated by hydrogen electrolysis, is the main operating cost included in the model. Capital costs, separations, compression, catalyst replacement, and CO_2 capture are excluded; therefore, the results represent an early-stage parametric screening rather than a full techno-economic assessment.

Results and discussion

Based on the three selectivity scenarios the quantities of all products are depicted in figure 1. The calculated total gross product values are therefore approximately €6461/t olefins for the 16% selectivity case, €5410/t olefins for the 21% case, and €4898/t olefins for the 24% case.

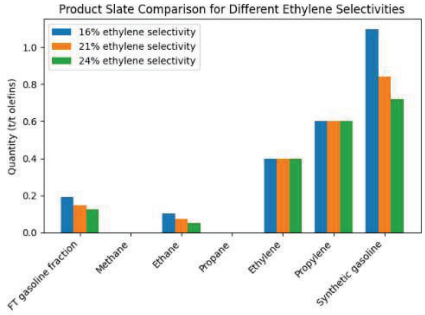


Figure 18. Products of all selectivity scenarios (16%,21%,24%)

The combined value of ethylene and propylene remains constant at approximately €963 per tonne of olefins, since the analysis is normalized to one tonne of total olefins. However, the value of secondary hydrocarbons and hydrogen decreases as selectivity increases. Residual hydrogen accounts for the largest share of gross product value in all scenarios, particularly at lower selectivity levels. This indicates that hydrogen management plays a critical role in determining the economic outcome of the process. If hydrogen is assumed to be recycled internally rather than sold as a co-product, the monetizable value of the product slate decreases substantially. Under these conditions, the monetizable value falls to approximately €2908/t olefins at 16% selectivity, €2406/t olefins at 21% selectivity, and €2165/t olefins at 24% selectivity. Finally, the effect of the electrolyzer type on the overall electricity cost was also examined (figure 2). It is evident that SOEC/SOFEC electrolyzer reduced the electricity cost for all cases examined by 30%

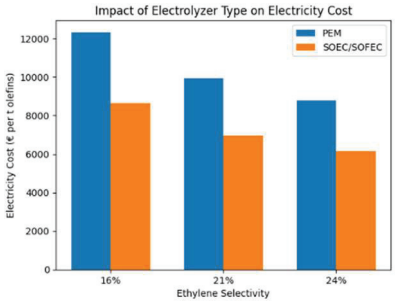


Figure 19. Impact of Electrolyzer Type on Electricity cost for 16%, 21% and 24% selectivity

Conclusions

This study demonstrates that the economic feasibility of light olefin production via electrification is highly sensitive to two key factors: reaction yield and electricity price. Since hydrogen generation through electrolysis represents the dominant energy demand of the system, electricity cost has a particularly significant influence on the overall process economics. At the same time, the carbon-negative potential of the technology and the availability of CO_2 credits may play an important role in improving its long-term economic viability. For large-scale deployment, securing access to competitively priced renewable electricity and optimizing conversion efficiency will be essential. If these conditions are achieved, the technology could offer a sustainable alternative to conventional olefin production routes and position early adopters at the forefront of the low-carbon transition in the petrochemical industry.

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